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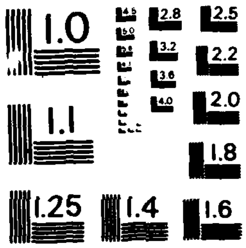

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The delineation of drainage gullies, in mapping operations, is a highly labor intensive effort. ETL has initiated a preliminary study to automate this manual task. This has led to a computer algorithm for extracting the drainage channels from digital elevation data. The algorithm, which is based on the theory of critical numbers, provides both the location and orientation of the gullies. This paper discusses the algorithm and and the preliminary results from three test cases.

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AUTOMATED GULLY DELINEATION USING DIGITAL ELEVATION DATA

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BIOGRAPHICAL SKETCH

Roberta Carroll received her B.S. degree in Mathematics from Indiana University of Pennsylvania in 1976 and her M.S. degree in Geodetic Science from Ohio State University in 1979. Currently, she is a cartographer with the Research Institute of the U.S. Army Engineer Topographic Laboratories. The emphasis of her work has been with computer-assisted photo interpretation research. Ms.Carroll is a member of ASP.

ABSTRACT

The delineation of drainage gullies, in mapping operations, is a highly labor intensive effort. ETL has initiated a preliminary study to automate this manual task. This has led to a computer algorithm for extracting the drainage channels from digital elevation data. The algorithm, which is based on the theory of critical numbers, provides both the location and orientation of the gullies. This paper discusses the algorithm and the preliminary results from three test cases.

INTRODUCTION

Rivers and streams carry the water from some 68.7 percent of the earth's landarea; therefore, the total number of drainage gullies is immense (Gregory, 1973). For the United States alone, there are over five million kilometers of river channels. This figure takes into consideration only those channels which would be considered as first order and higher on maps of a scale of 1/62,500 (Leet, 1971). Currently, the delineation of these channels, in mapping operations, is a highly labor intensive task and automation is necessary to decrease the production time and cost.

ETL has initiated a preliminary study, having as its objective, the automation of drainage delineation in the mapping process. The approach uses terrain elevation data, such as those which are currently produced automatically by the current map production systems. This elevation data is processed by an algorithm, which extracts both location and direction of drainage gullies.

DELINEATION METHOD

The computer algorithm for the delineation of drainage channnels solely from digital terrain elevation data is based on an idea similiar to the theory of critical numbers. In mathematics, a critical number, C, of a continuous function F is a value such that F(C) is a relative extremum for some closed interval [M,N] and either $M<C<N$ or $M>C>N$ (Johnson, 1970). An elevation value would be a relative extremum, if for some given neighborhood, it is either a maximum or minimum value. For gully delineation, the value must be a minimum; while, for ridge delineation only the maximums are considered.

Given digital elevation data in a matrix format, then by definition, the general neighbornood of the elevation value is its eight surrounding values. These eight values form four individual neighborhoods of the central elevation value. In Figure 1, consider E as the elevation value and points 1 through 8 as its surrounding values. The four neighborhoods of E to be examined are: [1,8], [2,7], [3,6], and [4,5].

1	2	3
4	E	5
6	7	8

Figure 1

Each of the neighborhoods must be considered since a drainage gully can have any one or a combination of the four directional orientations. If the test results prove E to be a minimum for any of the cases, then the appropriate tag is recorded. This tag represents both the location and orientation of the gully. The tagging code, which has been implemented in this program, is a binary system. A "1" is noted if the value is a minimum for the neighborhood, and a "0" otherwise. This scheme was organized in this manner to simplify the graphic subroutines. Using the above nine element matrix as an example, the four rules for the tagging scheme are:

1 - If E is a minimum when the neighborhood [1,8] is checked, then the tag is 0001.
2 - If E is a minimum when the neighborhood [2,7] is checked, then the tag is 0010.
3 - If E is a minimum when the neighborhood [3,6] is checked, then the tag is 0100.
4 - If E is a minimum when the neighborhood [4,5] is checked, then the tag is 1000.

Using the above rules on the element "422" of Figure 2, the tag would be 0010. This results since it was in the comparison of the neighborhood [425,425] for which "422" was found to be a minimum.

420	425	430
417	422	427
420	425	430

Figure 2

This tagging scheme allows for the previously mentioned multiple-orientation problem. For example, given the following elevation matrix of a gully with a two directional orientation, the tagging scheme, step-by-step, would yield:

101	85	85
120	90	100
130	85	120

Figure 3

1 - After checking the neighborhood [101,120] the tag becomes 0001.
2 - After checking the neighborhood [85,85] the tag remains 0001.
3 - After checking the neighborhood [85,130] the tag remains 0001.
4 - After checking the neighborhood [120,100] the tag becomes 1001.

Thus the resulting tag is 1001 - a multi-directional orientation.

In order to process large matrices of elevation data, the program first retrieves three consecutive columns of data. The algorithm then does the testing sequentially on 3 by 3 subset matrices, storing the resulting tags in a separate file. New columns of data are retrieved until the entire large matrix of data has been processed.

Figure 4 is an example of a set of elevation values. Figure 5 is its corresponding matrix of tagging values.

75	100	125	150	175	200	225
75	100	125	150	175	200	225
50	75	100	125	150	175	200
70	95	120	145	170	195	220
70	95	120	145	170	195	220
70	95	120	145	170	195	220

Figure 4

0	0	0	0	0
0010	0010	0010	0010	0010
0	0	0	0	0
0	0	0	0	0

Figure 5

The algorithm requires that each of the values, to be compared, has a full eight point surrounding neighborhood. Therefore, the first and last column and row of data are not processed. For example, the six row by seven column elevation matrix of Figure 4 has a corresponding tagging matrix comprised of four rows and five columns (Figure 5).

When the resulting matrix of tagging values is examined, both the location of the gullies and their directional orientation can be plotted. It must be noted that the directional flow of the stream channels is approximately 90 degrees from the position of the neighborhood which triggers the tag. This idea is demonstrated in the above figures. Consider north to be at the top of the page. From the tagging rules, the value 0010 indicates that the neighborhood north and south of the value triggered the tag therefore, the channel would have an east-west orientation. If similiar tagging values are connected, then the orientation trend of the gullies can be plotted. With a few modifications to the algorithm, a similiar ridgeline orientation map could be produced.

TEST DATA

In the testing of this algorithm, three elevation data sets were used. Two were manually created by overlaying a map with a transparent grid and interpolating the elevations directly from the contour lines at the grid intersection points. The grid had a fineness of 100 points per square inch. The third data set was a subset of the United States Geological Survey's Digital Elevation Model for the Hoopa, California area.

The first test case was a matrix of 900 elevation values (30 by 30), which was developed from a map of the Fort Belvoir, Virginia area. This map, Fairfax County/Section 108-2, which was compiled by Survey and Design, Inc. (Fairfax, VA) for the Mapping and Graphics Division of Fairfax County Government, had a scale of 1 inch to 500 feet. Therefore, the elevations were read every 50 feet for an area of 1500 feet by 1500 feet. The contour interval was 5 feet. This region was chosen as a test site due to the frequency and orientation of the drainage channels. One intermittent stream was symbolized on the map, but other gullies can be inferred from the V indentations of the contour lines (Strahler, 1975). This particular area was a good test site because the delineation of various channel orientations was tested.

The second test area was a 1200 value elevation matrix (30 by 40) which was developed from a 1:50,000 scale Defense Mapping Agency Topographic Center sheet of Nome, Alaska (Series Q701 571 Sheet 1650 II - Cross Country Movement Sheet of the Experimental Alaska Terrain Study). The same transparent 10 line per inch grid was used. Therefore, the 1200 values were read from a 12,500 by 16,667 foot area with data points read every 417 feet. The contour interval was 50 feet. This area was chosen because the stream channels tended to be

lengthy and have a variety of flow orientations.

The third test case was a 12,000 element matrix (150 by 80) which was subsetted from the large USGS Digital Elevation Model for the area of Hoopa, California. The spacing between the elevation values was 300 feet. This test case was used to demonstrate that automatically produced elevation data sets could be handled.

DISCUSSION

The following four figures exhibit a sample of the algorithm results using data from the second test case. Figure 6 is a small area of the Nome, Alaska 1:50,000 scale map. A section of the test region is outlined. The corresponding elevation data and resulting tag matrix are Figures 7 and 8 respectively. In Figure 9, the locations and orientations of the various gullies are plotted on the map from the information given by the tag matrix. The algorithm automatically tagged both the gullies which were symbolized on the map and those that could be inferred by the contour lines. Similiar results were demonstrated in the other test cases.

ALASKA ELEVATION DATA COLUMNS 1 TO 18

550.	440.	550.	650.	760.	900.	1050.	1175.	1300.	1350.	1240.	1150.	1050.	990.	910.	840.	750.	700.
648.	500.	530.	625.	750.	900.	1100.	1265.	1320.	1325.	1225.	1150.	1075.	1025.	950.	850.	750.	700.
725.	640.	550.	600.	750.	870.	1000.	1200.	1360.	1320.	1250.	1200.	1125.	1050.	960.	860.	760.	680.
850.	750.	675.	620.	750.	875.	1000.	1150.	1350.	1340.	1275.	1220.	1140.	1040.	950.	840.	750.	660.
975.	875.	800.	750.	825.	925.	1050.	1200.	1360.	1325.	1260.	1200.	1125.	1010.	925.	800.	725.	635.
1100.	1020.	965.	900.	920.	1000.	1125.	1300.	1360.	1300.	1250.	1175.	1100.	1000.	900.	775.	685.	600.
1125.	1135.	1100.	1050.	1050.	1110.	1240.	1360.	1350.	1275.	1200.	1125.	1050.	950.	850.	740.	650.	540.
1075.	1140.	1200.	1250.	1200.	1270.	1410.	1390.	1325.	1250.	1150.	1060.	975.	900.	780.	690.	600.	555.
1025.	1075.	1150.	1260.	1375.	1460.	1440.	1350.	1295.	1190.	1080.	1000.	925.	825.	740.	650.	550.	650.
925.	1000.	1100.	1200.	1340.	1335.	1315.	1275.	1220.	1125.	1025.	950.	875.	775.	700.	580.	600.	700.
925.	1000.	1090.	1200.	1250.	1225.	1210.	1200.	1150.	1075.	1000.	920.	840.	750.	650.	560.	680.	750.
1010.	1050.	1125.	1215.	1150.	1120.	1105.	1085.	1050.	1025.	950.	875.	780.	700.	625.	625.	730.	810.
1060.	1145.	1200.	1140.	1075.	1000.	990.	975.	950.	940.	890.	825.	750.	660.	590.	650.	740.	840.
1150.	1235.	1190.	1125.	1010.	910.	875.	885.	850.	840.	820.	760.	700.	640.	595.	675.	750.	850.
1225.	1250.	1190.	1100.	1000.	900.	800.	800.	760.	740.	725.	700.	675.	625.	620.	700.	760.	840.
1265.	1240.	1160.	1100.	1000.	920.	825.	735.	690.	665.	625.	640.	640.	600.	630.	700.	770.	825.
1260.	1220.	1150.	1080.	1000.	900.	800.	720.	725.	710.	675.	660.	650.	615.	645.	690.	750.	805.
1250.	1160.	1090.	1010.	940.	855.	750.	755.	765.	750.	725.	680.	675.	650.	635.	680.	730.	790.
1210.	1125.	1000.	950.	870.	815.	765.	815.	825.	810.	775.	740.	720.	690.	650.	675.	710.	775.
1240.	1140.	1050.	990.	900.	875.	790.	860.	875.	790.	840.	825.	800.	750.	710.	670.	690.	745.
1325.	1240.	1150.	1060.	985.	920.	830.	900.	930.	900.	950.	900.	850.	810.	760.	700.	680.	700.
1375.	1260.	1190.	1085.	1015.	950.	875.	900.	960.	985.	1100.	1000.	950.	870.	825.	755.	700.	725.

Figure 6

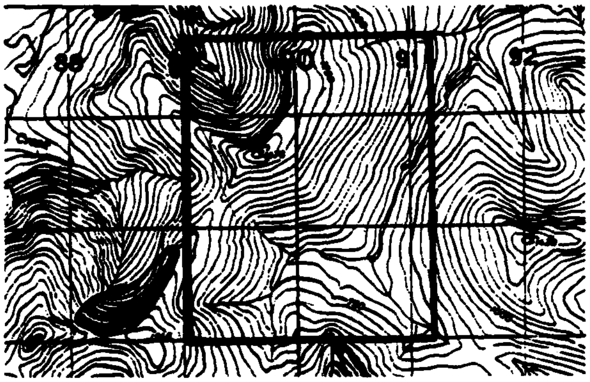

Figure 7

ALASKA DRAINAGE DATA COLUMNS 1 TO 16

1101	110	0	0	0	0	0	0	0	10	0	0	0	0	0	0
1	1100	110	0	10	0	0	0	10	0	0	0	0	0	0	0
0	0	1100	0	0	0	10	10	0	0	0	0	0	0	0	0
0	0	1000	100	0	0	0	0	0	0	0	0	0	0	0	0
0	0	1000	100	100	0	0	0	0	0	0	. 0	0	0	0	0
0	0	0	0	100	100	0	0	0	0	0	0	0	0	0	0
0	0	0	1000	0	0	0	0	0	0	0	0	0	0	0	1
0	0	0	c	0	0	0	0	0	0	0	0	0	0	0	1111
1	0	0	0	0	0	0	0	0	0	0	0	0	0	1001	1
100	10	0	0	0	0	0	0	0	0	0	0	0	0	1111	0
100	100	0	0	0	0	0	0	0	0	0	0	0	1	1	0
0	100	100	100	100	0	0	0	0	0	0	0	0	1111	0	0
0	0	0	0	100	1100	0	0	0	0	0	0	0	1101	0	0
0	0	0	0	10	110	100	0	0	0	0	0	1	1001	0	0
0	0	0	0	0	0	100	111	111	1111	111	10	1111	0	0	0
0	0	0	0	0	0	1011	1	0	0	0	0	1101	100	0	0
0	0	0	0	0	1011	1	0	0	0	0	0	0	1110	0	0
10	110	10	11	10	1001	0	0	0	0	0	0	0	1100	100	0
1	1	0	1	0	1101	0	0	1011	0	0	0	0	0	1110	100
0	0	0	0	0	1101	0	0	1000	0	0	0	0	0	0	1110

Figure 8

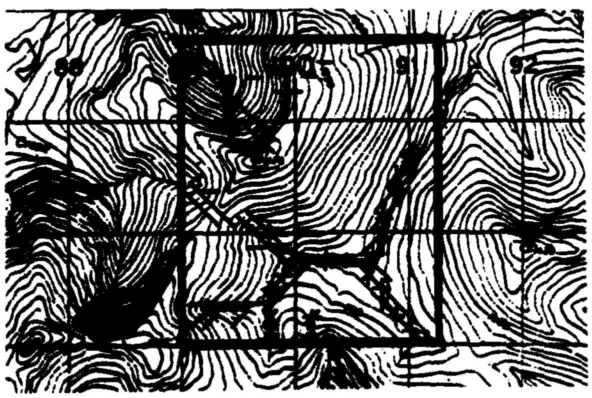

Figure 9

Currently, the algorithm is limited to those gullies not exceeding the spacing of the elevation values. Wide streams channels will be omitted. For example, if the elevation values are taken at a spacing shown by the x's in Figure 10, and the stream has the following profile, then it will be missed by the program. Further algorithm sophistication is necessary to correct this problem.

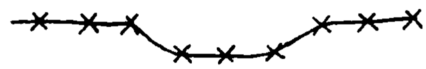

Figure 10

Figures 6 through 9 demonstrate another limitation of the current algorithm From the results, it appears that in the western section of the test area, there is a stream which is oriented north-west to south-east. Actually, there are two streams which are separated by a ridgeline. Therefore, it is planned to incorporate the ridgeline data with the gully location and orientation tags before plotting the results. With the ridgeline information added, watershed zones could also be delineated.

As with most work with elevation matrices, two of the important factors in this channel/ridgeline delineation technique are the quality of the elevation data and the distance separating the individual elevation values. If the input elevation data has errors, then the resulting gully map will not correspond to the actual ground it represents. Similiarly, if the area is undersampled, then the resulting map may miss actual gullies and/or ridges; since, the increased distance between elevation values results in a generalization of the topography.

CONCLUSIONS

From these preliminary results of the previously discussed test sets, it can be concluded that the process of automatically delineating gullies solely from elevation data has been successfully begun. Further sophistication of this gully delineation algorithm is planned, including the incorporation of ridgeline data and wide channel searches.

In the future, the automated delineation of a region's drainage channels and ridgelines will reduce labor intensive efforts, which occur in today's mapping operations.

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